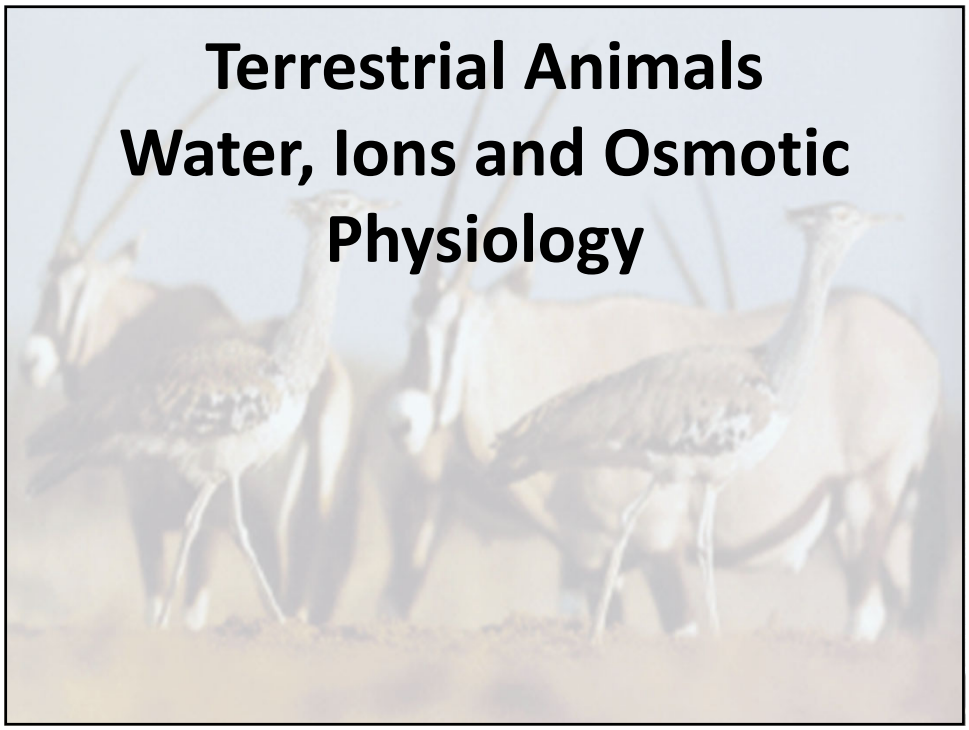
Terrestrial Animals
Water, Ions and Osmotic Physiology



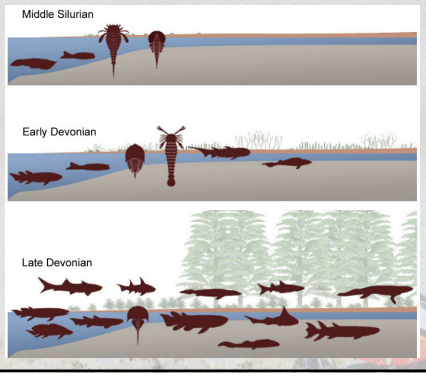
1

Water balance on Land

Prokaryote cyanobacteria
(>550 MYBP?)

Plants
(430 MYBP?)

Animals – needed something to eat
(<430 MYBP)



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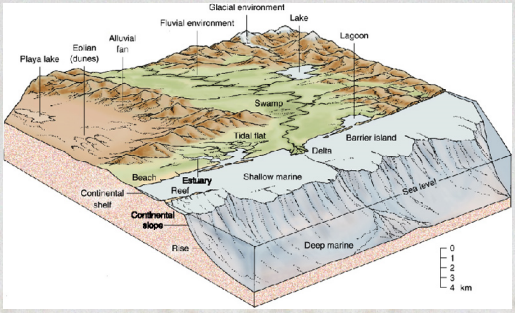
Aquatic-terrestrial transition

Problems:

- Evaporation: low RH
- High temperatures: critical thermal maximum
- Gas exchange in air: gills don't work anymore!



3

Physical challenges

Property	Water/aquatic	Air/terrestrial	Approximate ratio of water : air	
Density (g ml^{-1})	1.00	0.0012	850	gravity
Viscosity (kg m^{-1} s^{-1})	1.00	0.02	50	locomotion
Thermal capacity (J ml^{-1} °C^{-1})	1.00	0.0003	3300	thermal
Velocity of sound (m s^{-1})	1485	343	4.33	hearing
Refractive index	1.33	1.00	1.33	vision
Oxygen content (ml l^{-1})	4–7	210	1/30	
Oxygen diffusion ratio			1/300,000	respiration
Carbon dioxide content (ml l^{-1})	0.4	46	1/115	
Salts	Freely available	Not directly available		
Water	Abundant, but may be osmotically unavailable	Rare, always hard to find and keep		iono-osmo regulation
Food for plants	Only at surface	At all levels		
Food for animals	Throughout, all mechanisms possible	Throughout, but often hard to catch or eat		feeding

High Availability of oxygen in air →high metabolic rates

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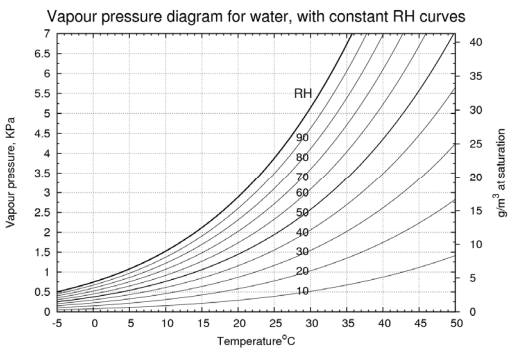
Evaporation

Evaporation occurs at RH < 100%

Evaporation is proportional to T_a and Dwvp



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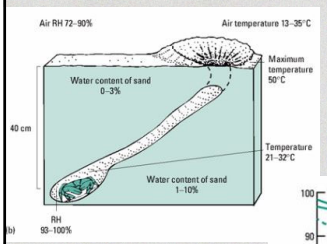
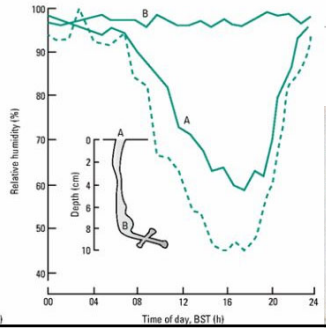
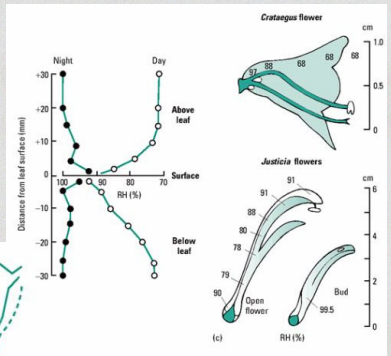
Humidity

Environmental RH typically < 100%







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Evaporative water loss in air is inevitable

- Can be minimised by increasing resistance of body surface helps, (but not respiratory surface)
- By adding a diffusive barrier
  → Reducing EWL/VO_2 at the surface interface

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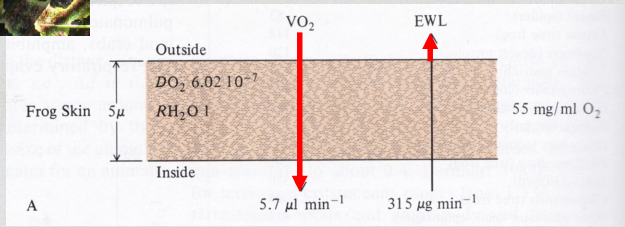
Evaporative water loss from a free water surface

Low diffusion resistance (R = 1 sec cm^{-1})
→ Frog skin is a negligable barrier to water loss



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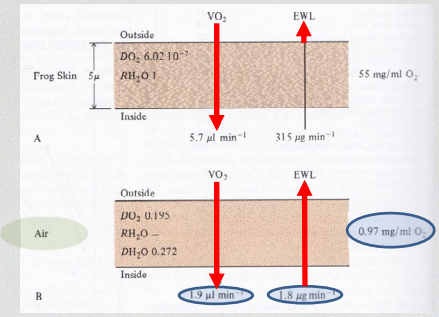
Reducing EWL from a surface

A still air barrier would work well, but animals use different strategies



55 fold improvement

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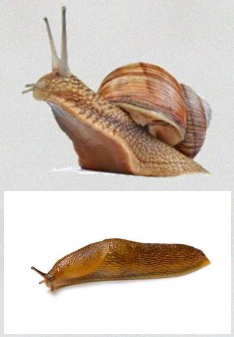
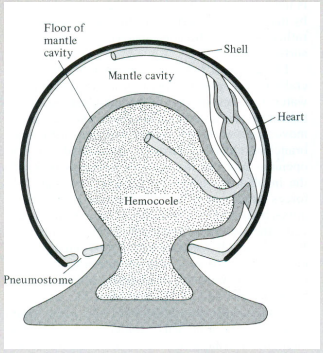
Pulmonate snails and slugs

Skin is free water surface (??)





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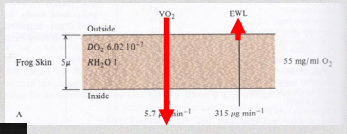
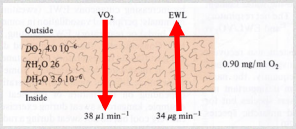
A snail epiphragm works almost too well





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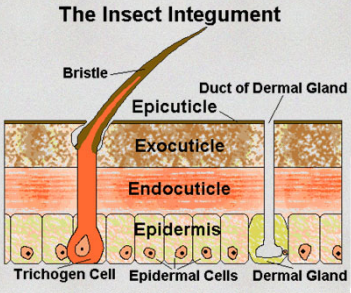
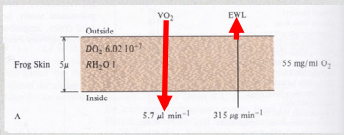
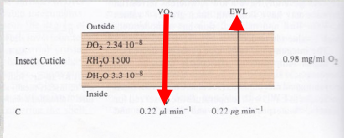
Insect cuticles have a water proofing layer







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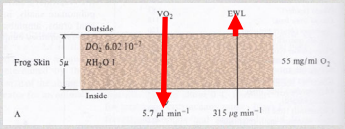
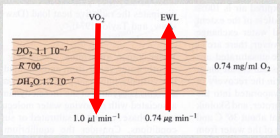
Frogs use dead skin as cocoon

and skin with stratum corneum
(reptiles, birds, mammals)



But it severely limits oxygen uptake



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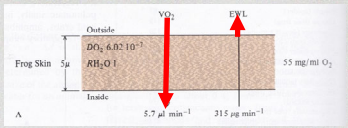
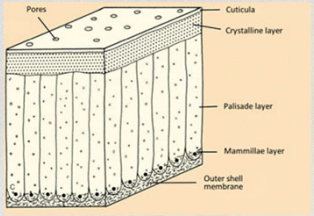
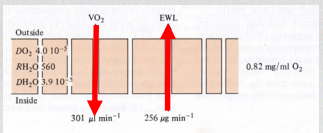
Bird shells are almost impermeable, but have pores







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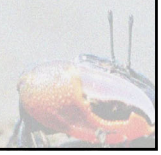
Summary

	R sec cm^{-1}	EWL/VO_2 mg/ml O_2
Frog skin	1 (outside)	55
Air barrier	1 (inside)	0.97
Frog cocoon	700	0.74
Snail epiphragm	26	0.90
Egg shell	560	0.82
Insect cuticle	1500	0.98



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What about Respiratory EWL?

Respiratory surface needs to remain moist
(for diffusive gas exchange across the surface)

- Lungs (vertebrates)
- Tracheole terminus (insects, etc)

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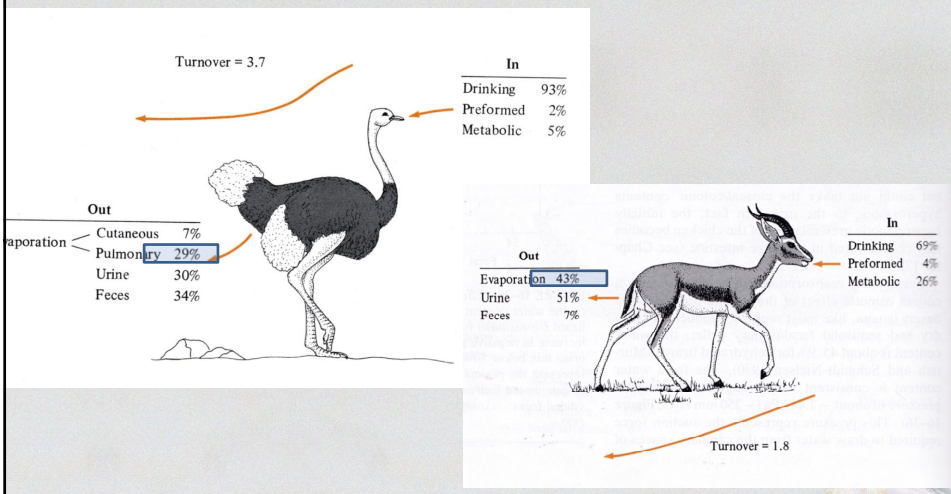
Mammals and birds respiratory water loss



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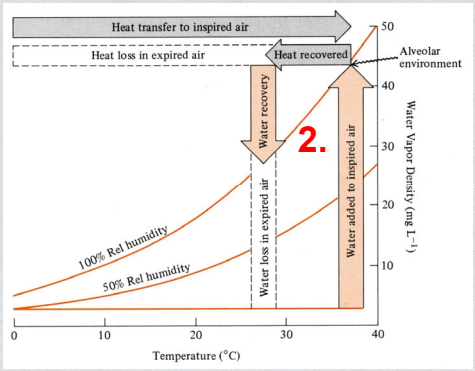
Expired vs inspired air: temperature and water content?

Nasal counter-current heat/water exchange



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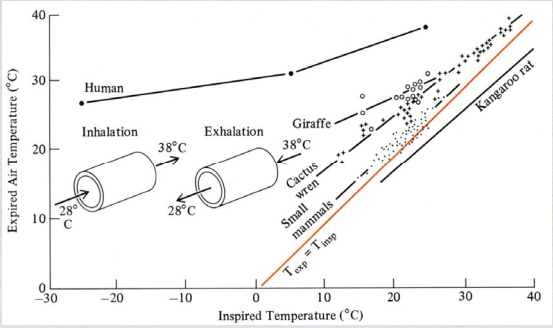
Expired Air is Cool (and 100% RH)



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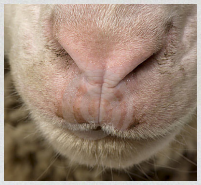
Not always 100% RH!?

(about 90%) for camels

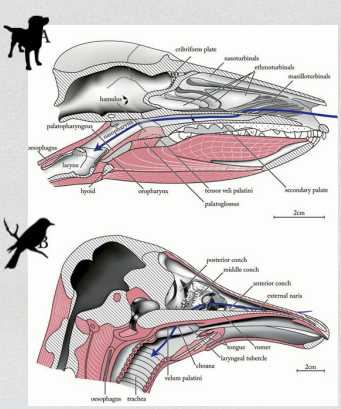
ostrich (85%)

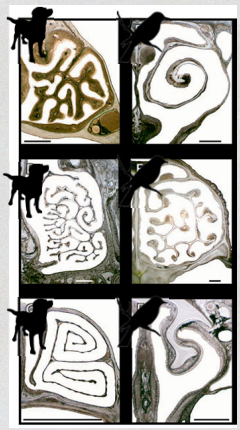


even sheep (85%)!

20

Nasal turbinates (endothermy)





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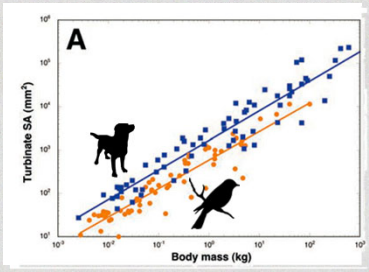
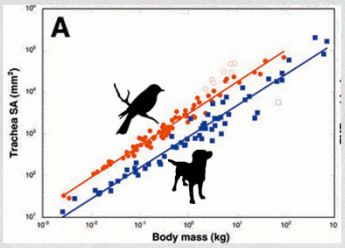
..... and Trachea

turbinate + trachea ≈ same





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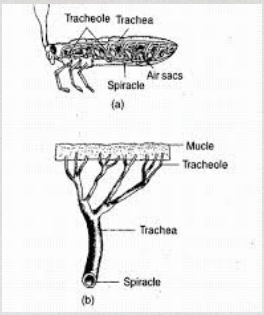
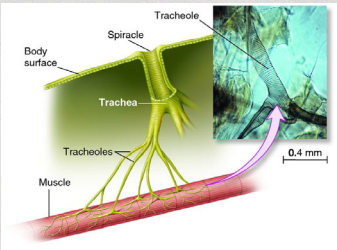
Insect trachea

In air: diffusive barrier of tracheal tubes





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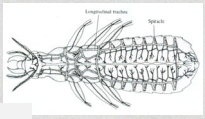
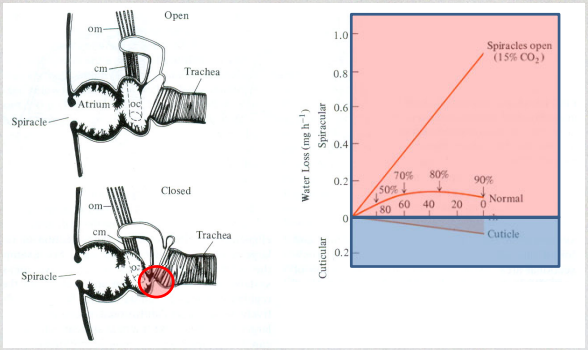
Insects

Tracheal system:
spiracle closure and water conservation





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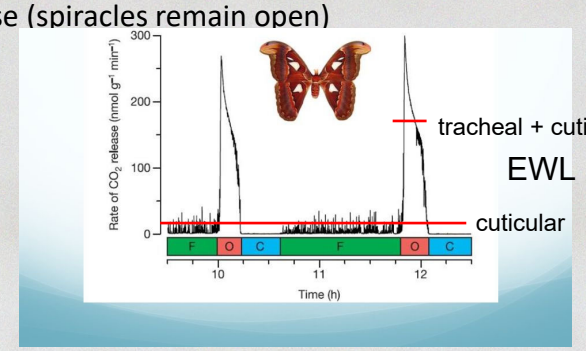
DGE (discontinuous gas exchange)

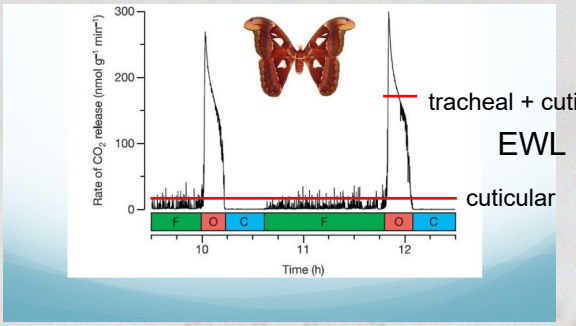
Closed phase (no gas exchange)

Flutter phase (spiracles flutter open and closed)

Open phase (spiracles remain open)



DGE (discontinuous gas exchange)

Why?

- Minimise EWL?
- Minimise toxic O2 damage when resting?